IRRIGATION TRIALS IN NEW MEXICO

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IRRIGATION TRIALS

Irrigation is generally taken for granted by most people here in the west. Often the people who irrigate need to know more about the land and how it takes and holds water. Each soil has a certain water holding cpacity. When it is full, any extra water added either runs off or, in some soils, goes below the plant roots and is lost for use by plants. On the other hand, some soils take water so slowly that they are not filled during the period of irrigation. On such soils the plants soon show stress and don't make rapid growth. To do a good job of irrigating we need to know several facts about the soil. How deep is the soil? How much water does it hold two days after an irrigation (net gain)? How fast can it take water (intake rate)? Do we need to remove salt from the root zone? Are we losing plant food? What difference does the cover or condition of the surface make in the rate and amount of water taken into a soil?

The trials reported here may assist you in answering some of these questions. Or perhaps, they may suggest how some of the answers might be obtained. Most of these trials were made on soils that take water well. The soils are usually underlain by rather infertile river sand at a depth varying between 20 and 36 inches. Roots are sparse or lacking in this sand. Consequently, these soils are limited in the amount of water and plant foods that they can store.

The results reported in this study have been selected from 26 facilitating soil moisture studies which were made before and after irrigation at the Soil Conservation Service Nursery near Albuquerque since 1945. The results from four similar studies made in the San Juan Soil Conservation District, New Mexico, and two in the Santa Fe-Sandoval Soil Conservation District are included. All of the studies made were in connection with border irrigation except those in the San Juan Soil Conservation District which were row irrigation and corrugation.

The following explanatory information pertains to the figures shown in this paper. The vertical scale showing the slope of the ground surface has been exaggerated. A horizontal dash line has been used to indicate the lower limit of the root zone. Field capacity expressed in inches of soil moisture per ten inches of soil (figure 1) may be obtained by following the right hand outer line of graph. The field capacity of the entire root zone for each third of the border may be obtained by adding the inches net gain with inches of soil moisture before irrigation.

Median discharge values have been reported since half of the individual values are above it and half are below it. Thus, an extreme value does not receive increased weight as it does if one uses an average.

Water application efficiency is calculated from the formula:

$$\text{Water application efficiency \%} = \frac{\text{Net gain in root zone}}{\text{Amount of water delivered to farm}} \times 100$$

The soil unit numbers used in this report are those defined in the conservation survey guide for Region VI.

Nitrate nitrogen and ammonia were determined on certain samples taken before irrigation and 2 days after irrigation at the Albuquerque Soil Conservation Service Nursery. The ammonia was determined by distillation of KCl extract. The nitrates were determined on a 1:5 CO_2 extract using phenol disulphonic acid method.

A detailed explanation of the procedures used will be given in a technical report.

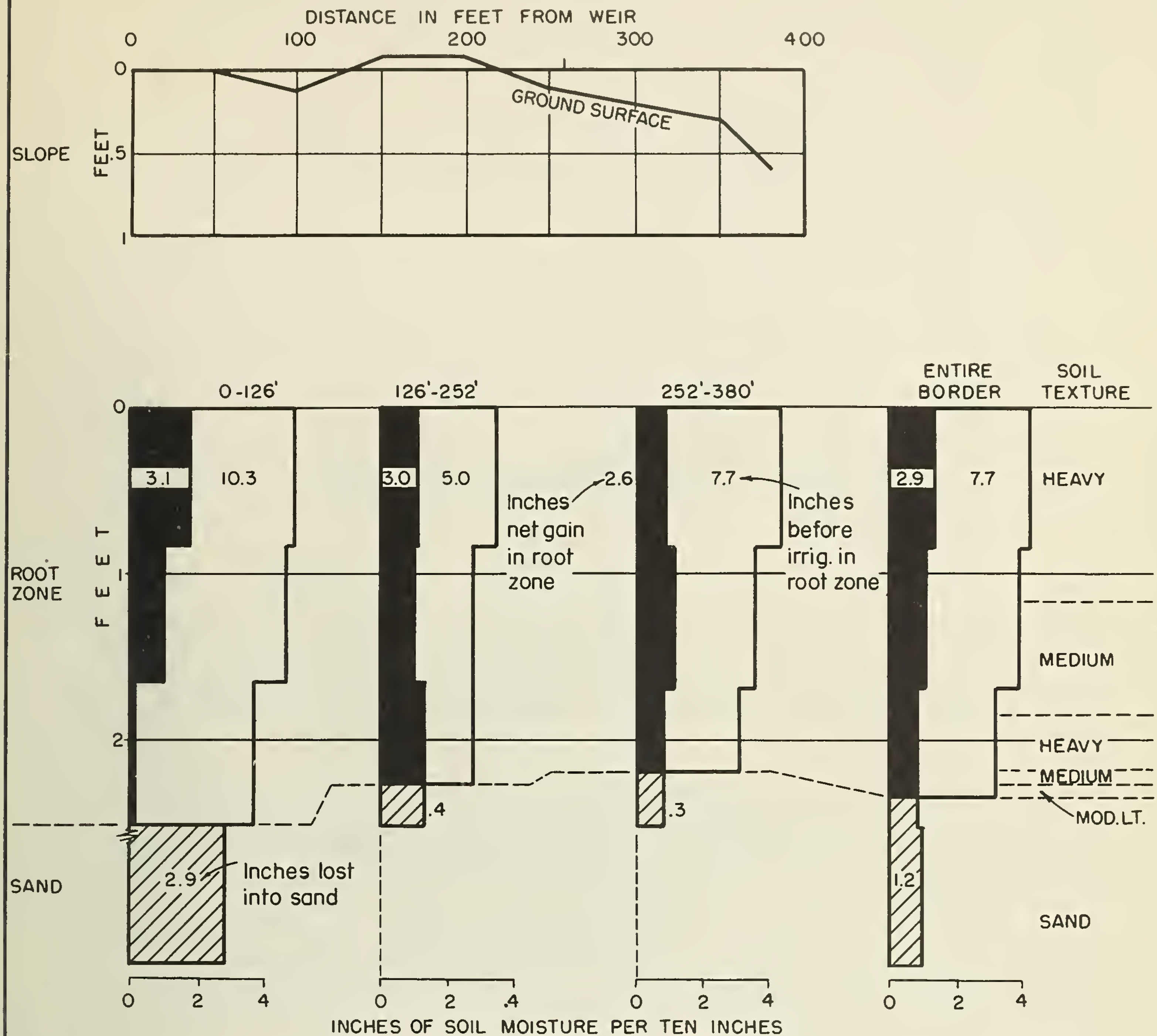
BORDER IRRIGATION-DISCHARGE 1.5-2.5 c.f.s.
High Spots on Permeable Clay, Soil Unit 13P2

One of the most important factors in getting the efficient use of water is to have an even surface. Remove the high spots. This study was set up to show the waste of water and soluble nitrogen that results on relatively short borders which have an uneven surface.

A border of weeping lovegrass, 36 feet wide and 380 feet long, was selected on a clay soil. You can see in figure 1 that there was a high spot 0.3 foot above grade in the middle third of the border. In each of the three irrigations studied, we attempted to get coverage of this uneven border with a minimum amount of water by shutting off the flow when the water reached a distance 260 feet from the weir. In selecting this point we were guided by the slope of the border, the difference in elevation between the high water line in the ditch and the highest spot on the border, supplemented by cutting the water off at a set point during previous irrigations.

The first trial, August 1, 1945, was made when the clay surface soil was badly cracked. Furthermore, there was a heavy grass mulch two inches thick as well as a heavy swath of hay left by the combine when the grass seed was recently harvested. The combination of the high spot and the heavy mulch forced most of the water to run around the high spot, so although 7.2 inches of water were applied, the middle third of the border gained only 0.7 inch of soil moisture. This area would have gained at least two inches of water from this irrigation if the high spot had been removed. The high spot and the mulch also resulted in an unsatisfactory irrigation in the upper third. Here there was a leaching irrigation with a loss of 8.0 inches of water into the river sand which lies below the root zone. Thus, this irrigation leached plant food in the upper and lower thirds of the border, whereas penetration was less than 20 inches deep in the middle third. Water application efficiency, as defined in page 1, was only 40%. Of course, such an irrigation was unsatisfactory but we were growing a perennial crop which we did not want to plow under in order to level the high spot.

The heavy mulch present in the first trial was believed to be contributing to heavy losses of water and soluble nitrogen into the underlying sand. So in March, 1946, before the second trial, the mulch was removed. On April 24, four sacks of ammonium sulfate (20.5%N) were



Net gain 2 days after irrigation

Before irrigation

Estimated loss into sand

Date May 21, 1946
Median discharge 2.1 c.f.s.
Water applied 4.5"
Time applied 37 minutes
Crop-weeping lovegrass, 20" high in rows 3' apart.

Cut off at 260' from weir
Size of area 36' x 380'
Water application efficiency 64%
Mulch-none

FIGURE I. Border irrigation trial on a clay topsoil, soil unit I3P2, uneven grade, field 3, border 5, SCS Nursery. The soil was badly cracked.

CONCLUSIONS: The 0.3' high spot should be cut and the border leveled to uniform grade. Removing the mulch increased water penetration in the middle third of the border but 76 pounds of nitrate nitrogen and 2.9" of water were lost into the sand from the upper third of the border.

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applied per acre with a drill and irrigated down with a 2.8 inch irrigation. The soil was moist prior to irrigation and good penetration occurred in the high spot area. Removal of the mulch allowed water to flow freely over the high spot and increased the irrigation efficiency appreciably.

The next irrigation was made on May 23, figure 1. The clay surface soil was badly cracked again, as in the first trial but the mulch had been removed. Although the minimum volume of water was applied, which would adequately cover the border, the upper third of the border received a leaching irrigation. Here, the high spot ponded water long enough to cause loss of nitrate nitrogen equal to three sacks of ammonium sulfate along with 2.9 inches of water from the root zone into the underlying river sand. The high spot caused a $10 loss per acre of fertilizer and a water application efficiency of only 64%. It is obvious that the high spot should be removed and the border leveled to uniform grade.

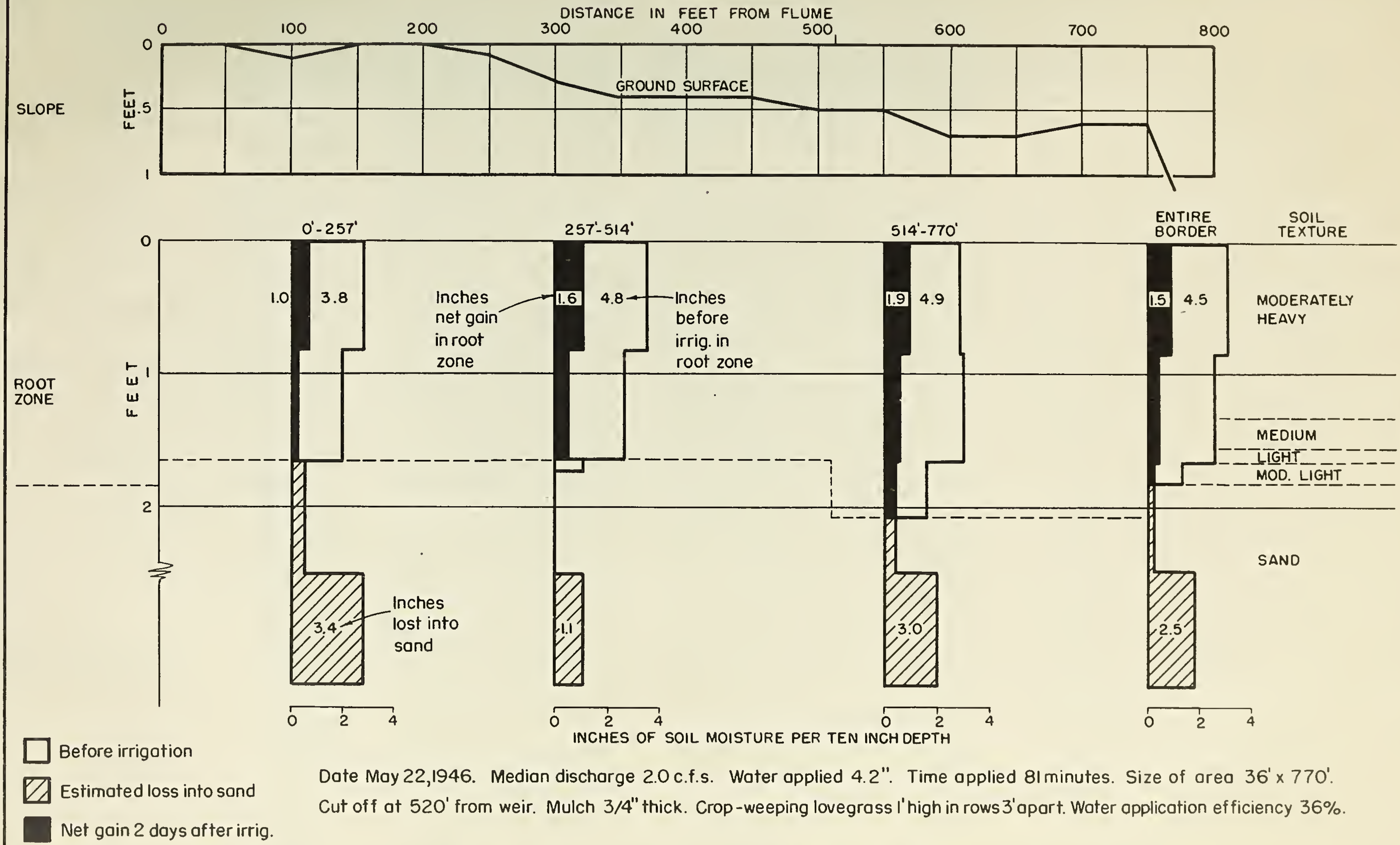
These three trials show that excessive losses of water and fertility occur on uneven borders, even though they are shorter in length than commonly recommended.

Uneven Long Run, Permeable Clay Loam, Soil Unit 24P2

We have observed in the preceding trials that an uneven surface caused excessive losses of water and soluble nitrogen especially in the upper third of a border 380 feet long. Would the location of such losses be any different in a border 770 feet long with an uneven surface? Such a study was made.

A border of weeping lovegrass, 36 feet wide and 380 feet long, was selected on a clay loam surface soil, soil unit 24P2. You can see in figure 2 that the grade was nearly flat in the upper third of the border and that there was a basin-like depression in the lower third of the border. If the slope were uniform, it would average 0.1%. In five out of six irrigations studied we attempted to get coverage of this uneven border with a minimum amount of water by shutting off the flow when the water reached a distance of 520 feet from the flume. In selecting this point we were guided by the same considerations that we used in the previous area.

The first trial, August 22, 1945, was made after the six-inch regrowth of weeping lovegrass had been wilting several days. At this time there was a grass mulch 1/2 inch thick. Under these conditions 66 minutes elapsed before the water reached the stake 520 feet from the weir. By this time 4.3 inches of water had been applied, and the 0-21 inch root zone storedonly 2.8 inches of soil moisture. Excessive penetration occured throughout the border except in the upper third of the border which has a low intake rate in late summer. If this border were cut in half, the minimum volume of water required for adequate coverage could be cut in half. If this were done, you could shut off the flow when the water reached a point 300 feet from the flume. This point was reached in 32 minutes, whereas an additional 34 minutes were required to advance the next 220 feet. Although this run was too long, we shall see more clearly in the following studies that the



Date May 22,1946. Median discharge 2.0 c.f.s. Water applied 4.2". Time applied 81 minutes. Size of area 36' x 770'. Cut off at 520' from weir. Mulch 3/4" thick. Crop-weeping lovegrass 1' high in rows 3' apart. Water application efficiency 36%.

FIGURE 2. Border irrigation trial on uneven long run, moist clay loam topsoil, soil unit 24P2, field 8, border 18, SCS Nursery.
CONCLUSIONS: Leveling to uniform grade and reducing the length of border would have reduced loss of 2.5" of water and the equivalent of two sacks of ammonium sulfate into river sand.

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uneven surface also resulted in low water application efficiency.

On April 24, 1946, eight sacks per acre of ammonium sulfate were drilled and irrigated down with 3.9 inches of water. The soil was moist prior to irrigation but the need for nitrogen could not be delayed without still further reducing seed yields. The water application efficiency of this irrigation was only 31% and was a leaching irrigation even in the upper third of the border. Apparently freezing temporarily improved the soil structure thereby increasing the intake rate; consequently, nitrate nitrogen equivalent to two sacks of ammonium sulfate were lost from the 0-30 inch depth. The highest losses of water occured in the nearly flat upper third and the basin like lower third.

The next irrigation, May 22, was made because at least one-fourth of the fertilizer was held in the dry surface inch. At this time, the weather was windy and the grass showed some stress although only half of the available moisture in the root zone had been used. You can see in figure 2 that the root zone of the entire border gained only 1.5 inches of soil moisture -- a water application efficiency of only 36%. Note that the uneven surface areas coincide with the greatest losses of water into the river sand. The losses of nitrates and ammonia were equivalent to three sacks per acre of ammonium sulfate in the upper third, two sacks in the middle third and $1\frac{1}{2}$ sacks in the lower third. This one irrigation resulted in a nitrogen loss of $7 per acre. Thus, our effort to make more nitrogen available to the plant was defeated by the uneven surface of a border which was also too long.

Since leaching irrigations could not be avoided on this field, six sacks per acre of ammonium sulfate were applied January 27, 1947, so that winter precipitation might carry the fertilizer into the soil. Insufficient rain and snow fell; consequently, the field was irrigated March 25. Another leaching irrigation resulted with losses of nitrate nitrogen and ammonia equivalent to two sacks per acre of ammonium sulfate in both the upper and lower thirds of the border. On this long, uneven border the water application efficiency was only 29%. As you would now expect the water application of the next irrigation on April 30 was a miserable 23%.

These irrigation trials show that on a long, uneven border, excessive losses of both water and fertility occur not only in the upper third of the border but also in the lower third of the border. These losses could be reduced by leveling the border to uniform grade and reducing the length of run.

Uniform Grade 0.1%, Permeable Clay, Soil Unite 14P2

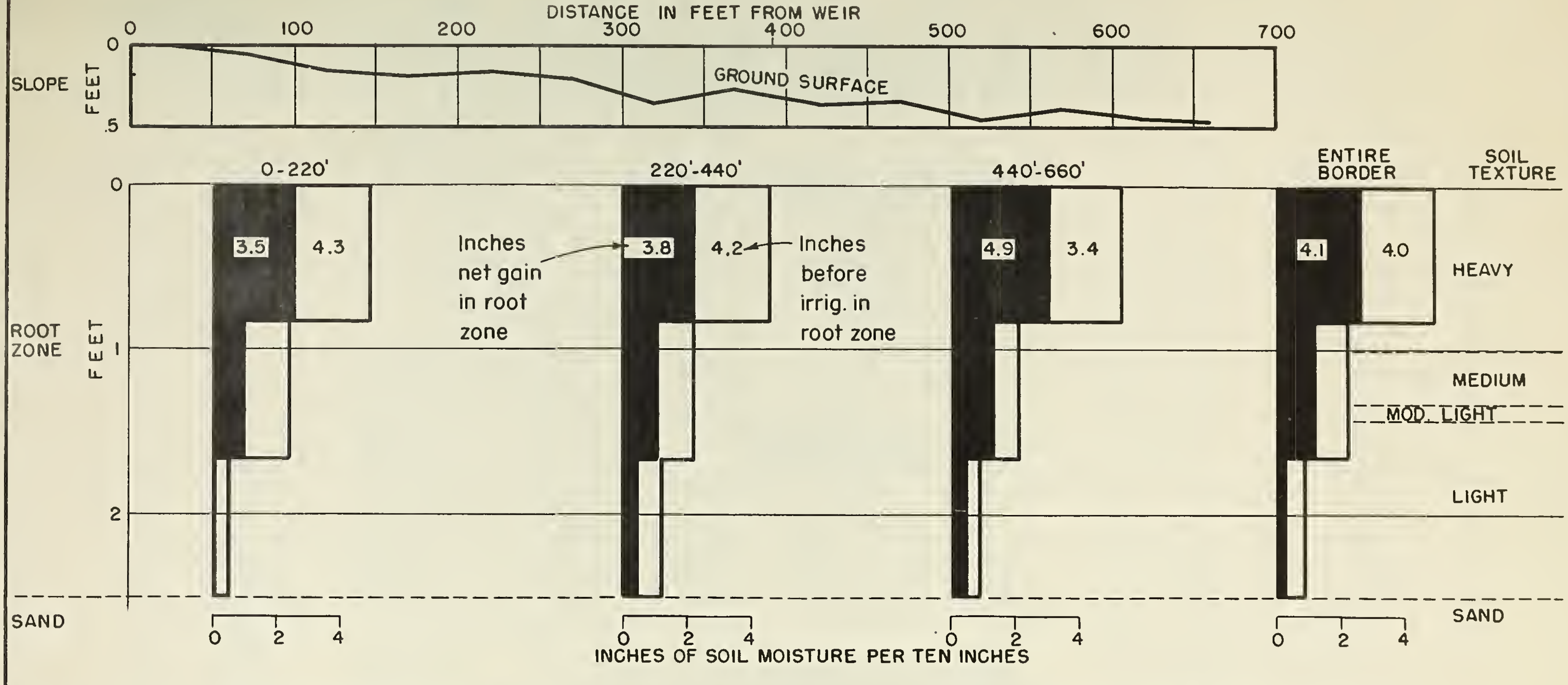
We have just shown that an uneven surface and too long a run resulted in leaching irrigations; consequently, we have recommended leveling to uniform grade and the proper length of run. Such an irrigation layout should result in the efficient use of water and nitrates, but leveling to uniform grade is not fool-proof. If soils of moderate water-holding capacity are irrigated when half of the available water is still present, leaching irrigations may result.

An area of moderate water holding capacity which had been leveled to a uniform grade of 0.1% (figure 3) was selected on a clay soil, 14P2. For this permeable soil, the length of run 660 feet was believed to be correct for borders 36 feet wide. In both of the two irrigations studied we obtained adequate coverage of this uniform grade border with a minimum amount of water by shutting off the flow when the water reached a stake 390 feet from the weir. A mulch 1/4 inch thick in 1946 tended to slow down the speed of the water and increase the intake rate.

On March 14, 1946, three sacks per acre of ammonium sulfate were applied to the tall wheatgrass. Owing to lack of rain, a four-inch irrigation was made on April 10 to carry the fertilizer into the soil. The same amount of ammonium sulfate was applied on April 24. For optimum seed production we believed that the roots should have this nitrogen at once. So, we irrigated May 1 although half of the available soil moisture was still in the root zone. Unfortunately, this 3.2 inch irrigation was a leaching irrigation and the water application efficiency was only 62%. The loss of nitrate nitrogen and ammonia from the root zone in the upper third of the border was equivalent to three sacks per acre of ammonium sulfate and the loss from the lower third was approximately two sacks. This irrigation not only caused the loss of nitrogen worth $6 per acre, but also defeated our purpose of using water and nitrogen efficiently.

The rapidly growing tall wheatgrass had shown stress several days before the next irrigation on May 22. The clay surface soil had cracked badly. You will see in figure 3 that the 0-30 inch root zone stored all of the 3.8 inch irrigation. There was no loss of water into the underlying river sand such as occurred on the uneven borders previously studied. In spite of the cracked surface soil, the uniform grade facilitated a good distribution of water. As you would expect, the changes in ammonia and nitrate nitrogen, before and after irrigation, were minor. Delaying the irrigation until the grass needed water resulted in efficient irrigation on this uniform grade border.

These trials show that a uniform grade border with the correct length of run for a permeable clay soil resulted in no loss of water and soluble nitrogen when the grass needed water. In contrast, appreciable losses of water and soluble nitrogen occurred when half of the available soil moisture was present prior to irrigation.



Net gain 2 days after irrigation.

Before irrigation

Date May 22,1946. Median discharge 2.2 c.f.s. Water applied 3.8". Time applied 58 minutes. Cut off at 390' from weir. Size of area 36'x660'. Crop-tall wheatgrass 2' high in rows 3' apart. Mulch 1/4" thick. Water application efficiency 100%.

FIGURE 3. Border irrigation trial on a badly cracked clay topsoil, soil unit 14P2, uniform grade 0.1%, field 2, border 7, SCS Nursery. The grass had shown signs of stress several days before irrigation.

CONCLUSIONS: This irrigation was satisfactory.

Uniform Grade 0.2%, Permeable Loam, Soil Unit 34P2

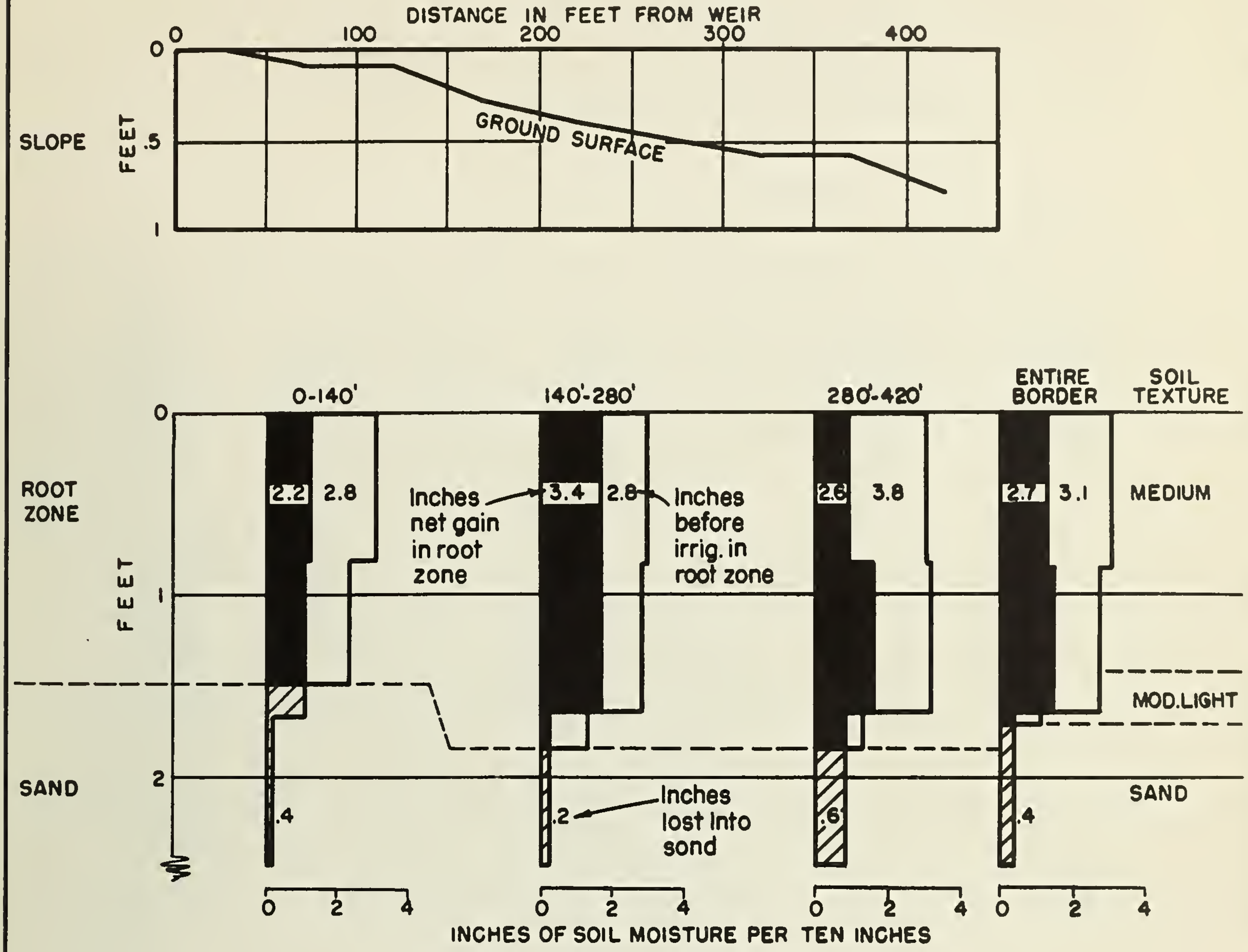
In the preceding study, a uniform grade border, 660 feet long was satisfactory on a clay soil. This soil has a lower intake rate than many medium textured soils. In general, as the intake rate increases, the length of run is shortened. Since borders 400 feet long on a uniform grade are often recommended for permeable medium textured soils, we wanted to know if such an irrigation system used water efficiently.

A border of sand lovegrass, 36 feet wide and 420 feet long, was selected on a loam, soil unit 34P2. Note in figure 4 that the uniform grade was 0.2%. In each of the four irrigations studied, we obtained adequate coverage with a minimum volume of water by shutting off the flow when the water reached a stake 300 feet from the weir. A mulch 1/2 inch thick slowed down the speed of the water and increased the intake rate.

Just as in the preceding study, we obtained the highest water application efficiency when the soil needed water. On May 29, 1946, we decided to irrigate this field because the grass was showing stress on other borders which were more sandy, however, the grass on the loam soil was not stressed. You can see in figure 4 that the root zone of this uniform grade border made an average gain of 2.7 inches from the 3.3 inch irrigation, a water application efficiency of 83%. Even this satisfactory efficiency could be increased by removing the mulch and floating this uniform grade border.

This high efficiency cannot be expected if the soil moisture is high in a root zone only 21 inches thick. However, to obtain excellent yields of grass seed, we have found it necessary to make large amounts of nitrogen available to the roots by a certain date. Accordingly, irrigations were made June 21 and July 5 in order to carry down four sacks of ammonium sulfate although the soil was moist. In both irrigations the root zone stored only two inches of water and the water application efficiency was but 61% . Appreciable losses of water into the sand occurred in both the upper third and lower third of the border. Owing to the rapid intake of nitrogen by the grass between irrigations, there was little nitrate nitrogen which could be lost. Since the water application efficiency was only fair on this uniform grade border when the soil was moist, we removed the mulch the following spring. Increased seed production in 1947 is attributed in part to the more efficient use of water and nitrogen.

Reducing the length of run to 400 feet gave efficient use of water on uniform grade borders on medium textured soils when the soil needed water. However, when the soil is moist and the storage available is small, leaching irrigations may be avoided by removing the mulch and floating.



Net gain 2 days after irrigation

Before irrigation

Loss into sand

Date May 29, 1946
Median discharge 2.1 c.f.s.
Water applied 3.3 inches
Time applied 35 minutes
Mulch 1/2 inch thick

Cut off at 300' from weir
Size of area 36' x 420'
Crop-sand lovegrass, rows 3' apart
Water application efficiency 83%

FIGURE 4. Border irrigation trial on a loam topsoil, soil unit 34P2, uniform grade 0.2%, field 12, border 5, SCS Nursery. The sand lovegrass was just beginning to grow and needed water on the moderately light parts of the field.
CONCLUSION: Removing the mulch and floating would increase water application efficiency.

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Flattened Grade, Permeable Fine Sandy Loam, Soil Unit 44P2

Since we have shown that efficient irrigation may be obtained by leveling to uniform grade, let us now consider a variation. On some soils the middle third of the border gains too little water. So, to increase the net gain in the middle third, the upper half of the border is leveled to uniform grade and the lower half is nearly flat level. We shall see that this scheme is unsatisfactory on the more permeable soils.

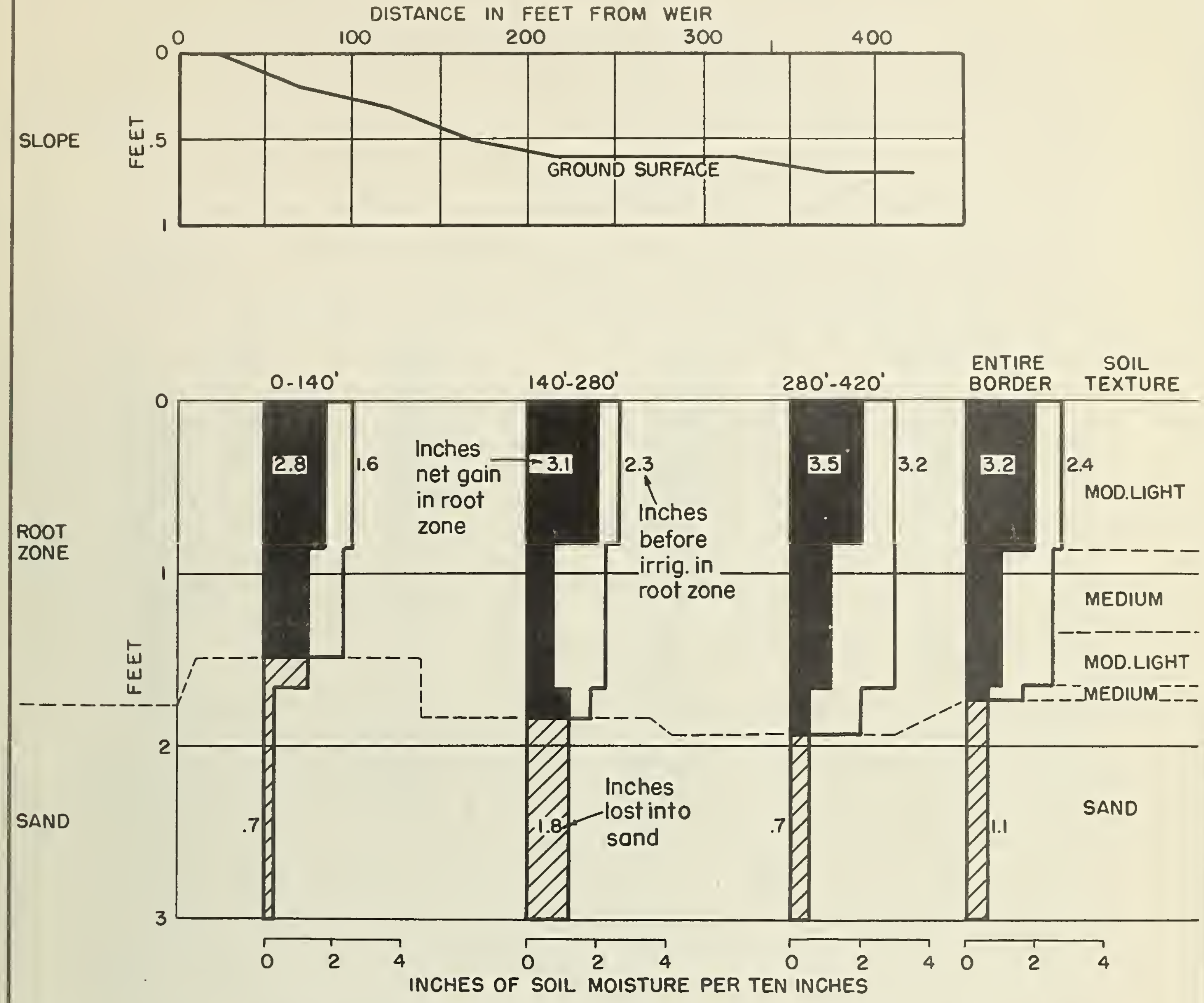
A border of sand lovegrass, 36 feet wide and 420 feet long, was selected on a fine sandy loam which almost approached a loamy fine sand in texture. You will observe in figure 5 that the upper half of the border has a uniform grade of 0.3%, whereas the lower half is nearly flat. In each of the five irrigations studied, we obtained adequate coverage with a minimum volume of water by shutting off the flow when the water reached a stake 340 feet from the weir. Thus, we had to let the water run 40 feet further on this flattened grade border than on the uniform grade border in the same field shown in figure 4.

The first trial was made, October 30, 1945, when the soil was dry. No regrowth of grass had occurred since the field was combined a month earlier. There was a mulch 1/4 inch thick as well as the hay left by the combine. Although good penetration was secured throughout the border from this 4.2 inch irrigation, 1.8 inches of water was lost into the sand in the middle third (figure 5). Thus, the flattened grade in the middle third caused an undue loss of water on a permeable soil of moderate depth.

Prior to the first irrigation in 1946, gophers had dug numerous holes. In order to cover the border adequately, it was necessary to apply 6.5 inches of water or nearly twice as much water as was applied usually. When a soil is underlain by rapidly permeable sand, you can see that gophers greatly increase the waste of water.

During the next three irrigations, which were made between May 29 and July 2, excessive waste of water occurred in the portion of the border nearly flat leveled. These losses from the root zone into the underlying sand averaged 1.4 inches in the middle third and 1.2 inches in the lower third. The water application efficiency for the three irrigations averaged 68%. Just as in the border shown in figure 4, there was very little nitrate nitrogen present at the time of irrigation. Thus, the nitrogen loss was small in spite of leaching irrigation on this flattened grade border.

From these five trials we may conclude that changing from a uniform grade in the upper half to a flattened grade in lower half resulted in excessive water loss in the flattened portion on a permeable soil of moderate depth.



- Net gain 2 days after irrigation
- Before irrigation
- Loss into sand

Date Oct. 31, 1945
Median discharge 1.5 c.f.s.
Water applied 4.2 inches
Time applied 51 minutes
Crop-sand lovegrass, rows 3' apart

Cut off at 340' from weir
Size of area 36' x 420'
Water application efficiency 76%
Mulch 1/4" thick

FIGURE 5. Border irrigation on fine sandy loam topsoil, soil unit 44P2, flattened grade, field 12, border 12, SCS Nursery. The sand lovegrass had been combined. The soil was very dry.
CONCLUSIONS: Leveling to uniform grade, increasing the discharge and removing the mulch would help to reduce excessive water losses.

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BORDER IRRIGATION - DISCHARGE 4-5 c.f.s.

Uniform Grade 0.1%, Permeable Loam, Soil Unit 34P2

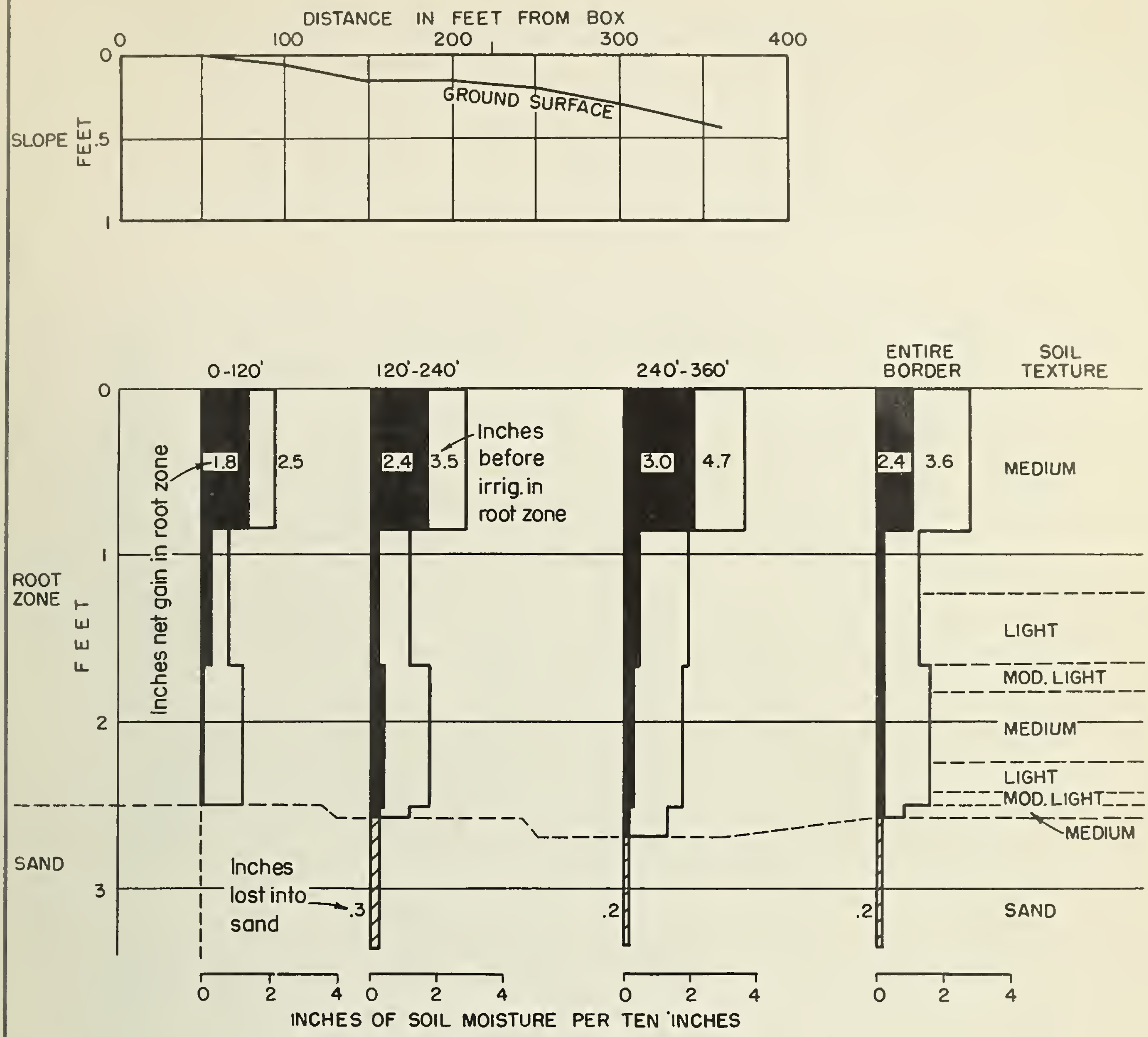
You observed in the preceding studies that we used flows of 2 c.f.s. on a wide range of permeable soils which were underlain by sand at a depth varying from 20 to 30 inches. Since we usually had to irrigate down the nitrogenous fertilizer before the grass needed water, appreciable losses of both water, nitrate nitrogen and ammonia, occured in the root zone even on uniform grade borders of proper length. You will recall that such losses were much greater on uniform borders. Thus, our irrigation system was not sufficiently flexible to apply just enough water to carry the fertilizer into the soil. Accordingly we set up a facilitating study at the Soil Conservation Service Nursery to determine how much less water could be applied using a flow of 5 c.f.s.

A border of intermediate wheatgrass, 50 feet wide and 360 feet long, was selected on a medium textured surface soil. Note in figure 6, that the ground surface has a uniform grade of 0.1%. There was no mulch on this area. In the spring of 1947, the root zone was less than 25 inches deep and was comparable to other young row crops. By fall, the roots had penetrated to 32 inches and were comparable to a mature row crop. Owing to the heavy fertilization and subsequent enrichment of the river sand in 1947, a few roots were found in the sand to a depth of 40 inches in April, 1948.

The first trial, May 13, 1947, was made when the new planting of intermediate wheatgrass had shown stress several days before irrigation in the upper two-thirds of the border. Using a flow of 4.9 c.f.s., 2.5 inches of water were applied in 12 minutes; the water disappeared at a rate close to four inches per hour in the upper one-third of the border. Owing to the small amount applied as well as the short period of time that the water remained on the upper one-third of the border, numerous spots of dry subsoil were found two days after irrigation. Although large quantities of nitrogen were present, there was no appreciable change before and after irrigation. In contrast, the entire root zone in the lower one-third of the border was wet and the loss of soil moisture into the river sand was 0.2 inches (figure 6). In spite of this small loss, nitrate nitrogen equivalent to six sacks of ammonium sulfate per acre moved downward from the 0-30 inch depth into the 30-40 inch depth beyond the young roots. For this young grass, slightly less water should have been applied; however, the water application efficiency was very high.

In succeeding irrigations we continued the use of large volumes of water for short periods of time which only penetrated to a shallow depth in the upper two-thirds of the border. Although an abundance of nitrogen was present, insufficient moisture in the subsoil may account for seed production being smaller in borders which had less nitrogen but better moisture penetration.

In spite of unusual winter moisture, this uniform grade border showed severe stress by April 21, 1948, when it was irrigated. The grass had



Net gain 2 days after irrigation	Date May 13, 1947	Time applied 12 minutes
Before irrigation	Median discharge 4.9 c.f.s.	Cut off at 225' from box
Loss into sand	Water applied 2.5 inches	Size of area 50' x 360'

Water application efficiency 96%. Mulch-none.
Crop-Intermediate wheatgrass, 5" high, rows 3' apart.

FIGURE 6. Border irrigation trial on uniform grade 0.1% with loam topsoil, soil unit 34P2, field 11, border 4, SCS Nursery. The new planting showed stress.

CONCLUSIONS: In spite of a high water application efficiency, 122 pounds of nitrate nitrogen moved from the higher layers into the 30-40 inch depth in the lower third. The discharge should have been lower and the water should have been cut off at the 200 foot mark.

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again shown severe stress for several days when 3.1 inches of water were applied May 12 in 22.5 minutes using a flow of 3.4 c.f.s. In the upper two-thirds of the border the root zone made a net gain of only two inches, although the water stayed on the border 1.1 hours; thus showing that the intake rate had dropped to 1.8 inches per hour. In the same area, moisture had penetrated to a depth of only 14 inches two days after irrigation. Thus, we did not get sufficient penetration although we probably held our nitrates near the surface where the roots are most abundant.

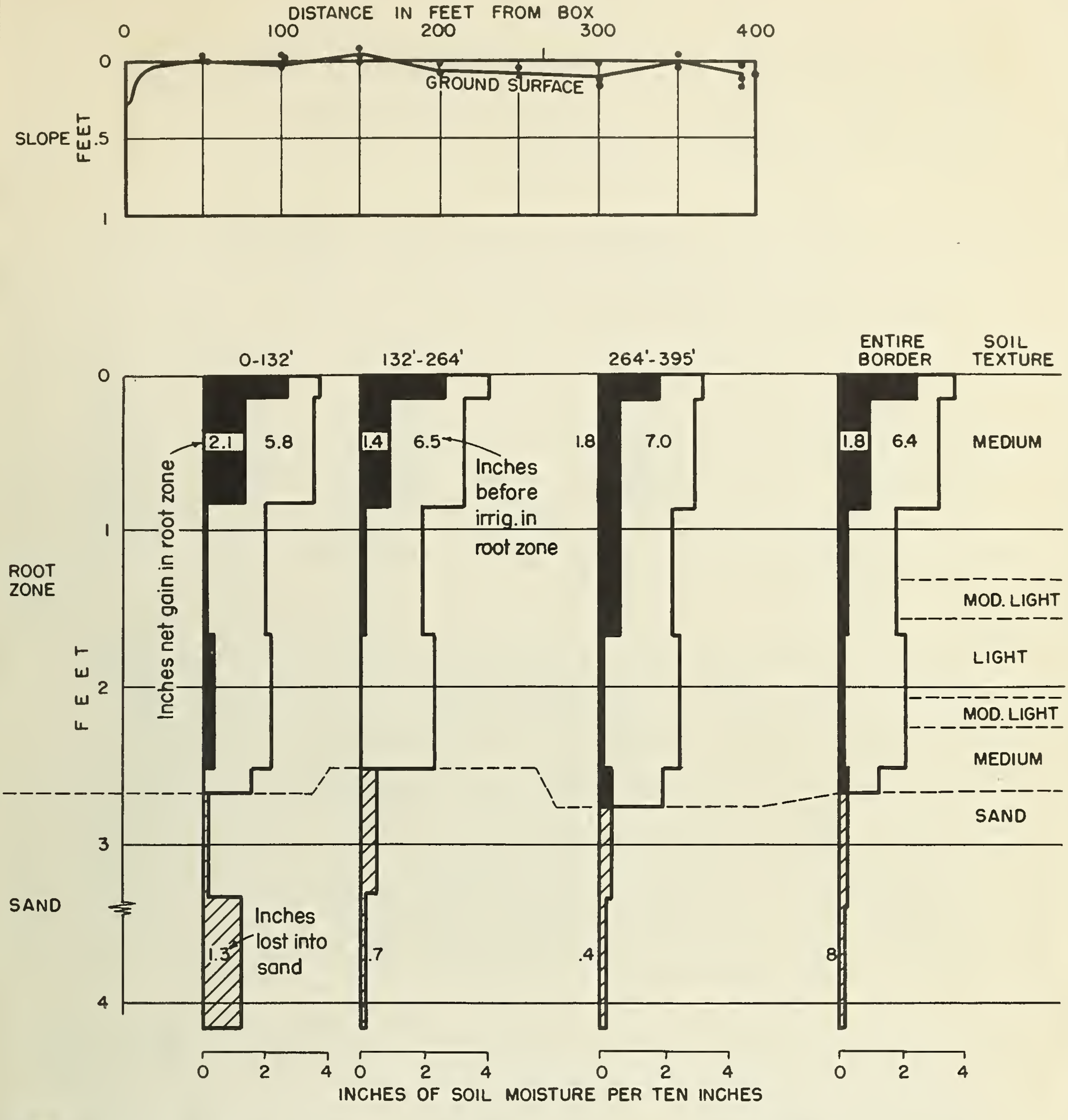
Next, we considered reducing the flow to 2 c.f.s. or less but this would have resulted in leaching the nitrogen from the lower part of the border, as well as wasting water. So, on May 26 we built a check across the border 225 feet from the ditch. To this area we applied 4.4 inches of water using a flow of 4.9 c.f.s. After 2.5 hours most of this water had gone in and we turned in more water. This time we opened the cross check in order to irrigate the lower one-third of the border. For the entire border we applied a total of 4.2 inches in 23.2 minutes during the two flows. Above the cross check the moisture penetrated to a depth of 26 inches or 12 inches farther than the preceding irrigation. In addition two inches more water were stored in the root zone than from the preceding irrigation. The water application efficiency of this irrigation was 88%. Thus, we have a feasible system of applying either large or small amounts of water as needed but more skill is required by the irrigator.

For shallow young root systems and for those irrigations in which we wish to retain all of our nitrogen in the root zone we can obtain adequate coverage of this 0.1% uniform grade border with 2.5 inches of water using a flow of 4.5 c.f.s. At least 25% more water would be required if we used flows of 2 c.f.s; furthermore, we might leach out nitrogen costing $7.00 per acre in a single irrigation.

From the three irrigation trials we may conclude that using large flows of water up to 5.0 c.f.s. on a uniform grade of 0.1% will result in the efficient use of water and conservation of nitrogen on moderately permeable soils of moderate depth. However, inadequate penetration will occur if the intake rate drops below three inches per hour. Under these conditions split applications and cross checks appear desirable.

Flat leveled, Permeable Loam, Soil Unit 34P2

The other part of the study just described, using flows of 5 c.f.s. on soils of moderate intake rates, was to flat level part of the same field. The advantage of flat leveling over uniform grade is that the water stays on the entire border a more uniform length of time. Consequently, less experienced irrigators can be used. On the other hand, flat leveling may cost twice as much as leveling to uniform grade and deeper cuts are made. If the top soil is underlain by sand or other materials of either low water holding capacity or low fertility, a deep cut may reduce yields.



Net gain 2 days after irrigation

Before irrigation

Estimated loss into sand

Date May 13, 1947
Median discharge 4.9 c.f.s.
Water applied 2.8 inches
Time applied 15 minutes
Cut off 270' from box
Size of area 50' x 395'
Crop-Intermediate wheatgrass 5" high and in rows 3' apart
Water application efficiency 62%
Mulch-none

FIGURE 7. Border irrigation trial on an area flat leveled with a loam topsoil, soil unit 34P2, field 11, border 8, SCS Nursery. The young planting had shown stress a week earlier but recovered after a light shower. CONCLUSIONS: Minor leveling is needed to eliminate the high spots.

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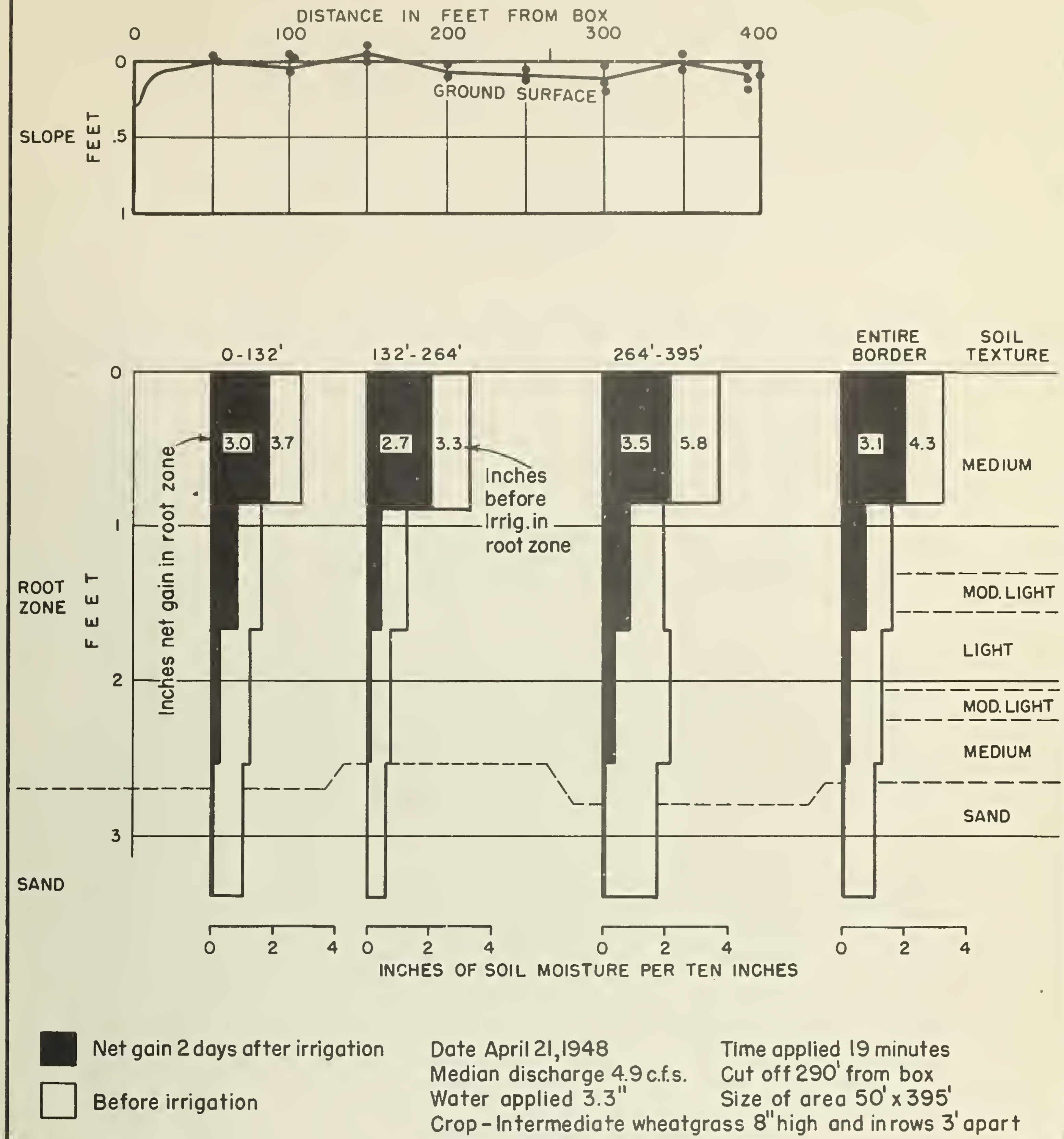
A flat leveled border of intermediate wheatgrass, 50 feet wide and 395 feet long was selected on the same soil, 34P2, as the uniform grade border. You can see in figure 7 that high spots of 0.1 foot developed at 150 and 350 feet from the ditch. Even excellent leveling jobs usually need floating within a year.

The first trial, May 13, 1947, was made shortly after a light shower during which the young plantings of intermediate wheatgrass recovered from stress previously shown for several days. Using a flow of 4.9 c.f.s. 2.8 inches of water were applied in 15 minutes. At this time, the water had covered 270 feet of the border but failed to cover a small high spot near the farther end. In contrast to the uniform grade border, both the greatest gain and greatest loss of soil moisture occurred in the portion nearest the ditch (figure 7). Here, nitrogen equivalent to two sacks of ammonium sulfate were lost from the root zone. Although the young grass had shown stress, the potential root zone contained twice as much moisture before irrigation as the uniform grade border. We attribute the unsatisfactory water application efficiency of 62% to the failure of the roots to penetrate deeply and to the high spots which required nearly .5 inch more water. Obviously the high spots should be floated out.

On April 21, 1948, the intermediate wheatgrass showed stress in the upper half of the border but on a smaller area than the uniform grade border. A more mature root system had pulled out three inches more moisture from the 0-40 inch depth than it had a year ago when the grass showed stress. On April 21, 3.3 inches of water were applied in 19 minutes at a rate of 4.9 c.f.s. As in the other flat leveled borders, the water had covered 75% of the border when the flow was shut off. Although adequate coverage was obtained at the farther end, the high spots were soon bare; dry soil was found in these areas at a depth of 15 inches two days after irrigation. Otherwise the distribution of water was excellent (figure 8) and the water application efficiency was high -- 94%. This sharp increase in efficiency over that of a year ago is due to the deeper root system drawing the soil moisture from a greater depth.

At the next irrigation, May 12, the grass again showed stress in the vicinity of the high spot 150 feet from the ditch. Using a flow of 5.2 c.f.s., 3.4 inches of water were applied in 18 minutes. The water stayed on the border 3.1 hours as compared with 2.2 hours during the previous irrigation. Thus, the intake rate decreased from 1.4 inches per hour to 0.8 inch per hour. Just as in the other fields the first irrigation of the season had the highest intake rate. This is attributed primarily to the favorable temporary effect of freezing on soil structure which is lost in the succeeding irrigation. Once more dry soil was found two days later under the 0.1 foot high spots at a depth of 16 inches. Otherwise, the distribution of water was satisfactory and again the water application efficiency was high -- 94%.

On other permeable soils, we had found it desirable to cut off the flow when the water reached a set point in order to apply a minimum volume of water. So, in this flat leveled field where borders were 50 feet wide and varying from 265 feet to 545 feet in length, we shut



Date April 21, 1948
Median discharge 4.9 c.f.s.
Water applied 3.3"
Time applied 19 minutes
Cut off 290' from box
Size of area 50' x 395'
Crop - Intermediate wheatgrass 8" high and in rows 3' apart
Water application efficiency 94%
Mulch - none

FIGURE 8. Border irrigation trial on an area flat leveled with a loam topsoil, soil unit 34P2, field 11, border 8, SCS Nursery. The grass had shown stress in the upper half of the border. CONCLUSIONS: Excellent distribution and penetration occurred except in high spot areas which should be floated out.

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off the water when 75% of the borders were covered. This procedure resulted in adequate coverage of these borders using flows varying from 4.6 to 5.2 c.f.s. which is about 2,000 gallons per minute. We applied approximately four inches of water on borders 500 feet long; 3.5 inches on borders 400 feet long; and three inches on the borders 295-370 feet long. Three inches of water was not sufficient to wet the subsoil under 0.1 foot high spots on those borders less than 400 feet long. With this exception, it was satisfactory to cut off the flow on 34P2 soils when 75% of these flat leveled borders were covered with water.

Another important problem is the proper length of run since longer runs reduce cost of operating farm machinery and the number of ditches. On a per-acre basis borders flat leveled, 50 feet wide and 300 feet long, took as long to irrigate as borders 500 feet long when we applied 3.5 inches of water. Although the maximum net gain for this 34P2 soil could be five inches of soil moisture, we would ordinarily irrigate before severe stress when the root zone might hold four inches. Thus, a 3.5 - 4 inch application would ordinarily avoid leaching of the plant food and the excessive loss of water from the root zone. Our studies indicate that flat leveled borders 500 feet long are the maximum length for high efficiency on this permeable 34P2 soil for crops with root systems fully occupying the root zone.

If we had had shallow, permeable soils with an available storage capacity of less than 2.5 inches, using 5 c.f.s. on flat leveled borders would not be efficient irrigation. The minimum volume of water which would consistently cover flat leveled borders less than 420 feet long was three inches. The presence of high spots 0.1 - 0.2 feet high, affected the amount applied more than differences in length of run.

There is not only a saving of water and nitrogen by using flows of 4.5 - 5.0 c.f.s. on permeable soils but there is also a saving in time. Applying the minimum volume of water required to cover a border adequately (young crops with shallow root systems on shallow soils) we could irrigate four times more land on a uniform grade than when we used 2 c.f.s. We could likewise irrigate three times more land on the flat leveled borders. For mature crops requiring more water we are able to apply 3.5 inches of water on the flat leveled border at the rate of 1.3 acres permhour. Other years, using 2 c.f.s., more than twice as long would have been taken to have irrigated the same size area with narrower borders (36 feet wide). Assuming eight irrigations per year at 75 cents per hour for an irrigation, one could save from $5.00 to $8.00 per acre in labor annually, using flows of 5 c.f.s. as compared with flows of 2 c.f.s.

These irrigation trials on flat leveled borders show that efficient use of water can be obtained using flows of 5 c.f.s. on permeable soils of moderate depth. Savings in water, plant food, labor, and less experienced irrigators must be balanced against high leveling costs and depth of soil left after leveling.

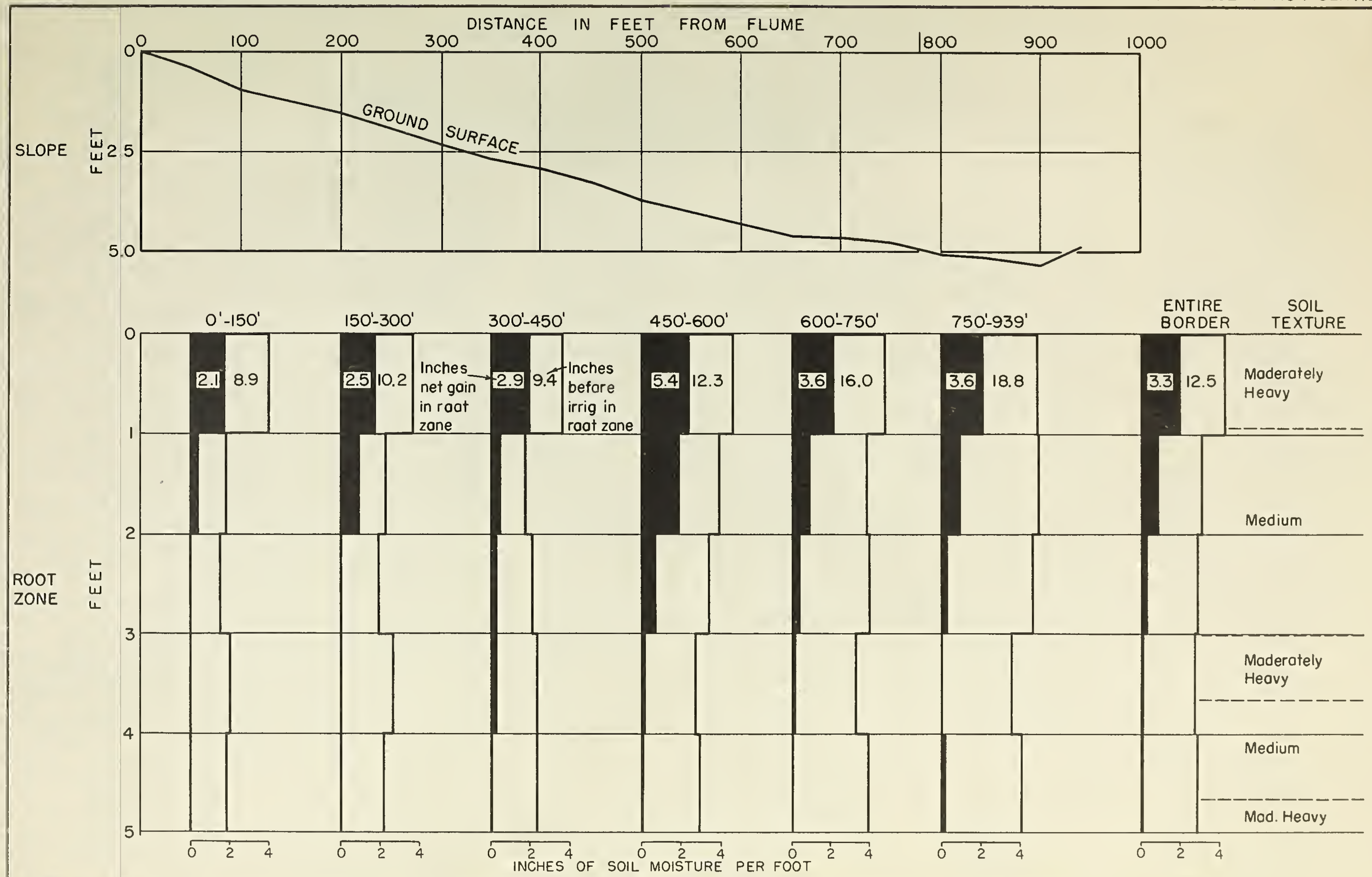
BORDER IRRIGATION - DISCHARGE 1.0-1.5 c.f.s.
Two Grades (0.7 and 0.2%), Permeable Clay Loam, Soil Unit 2321

All of the preceding irrigation trials on the heavier soils were on slopes of about 0.1%; the size of the streams of water used varied from 2.0 to 2.3 c.f.s. Here, the water may remain on the upper third of the border for an hour or more after the flow of water has been shut off, thereby increasing penetration. In contrast, on somewhat steeper lands the water runs off the upper third within a few minutes after the flow is shut off. Therefore, a smaller stream of water is used for a longer period of time in order to get deeper penetration. However, if too small a flow is used and if there is too much side slope, it will be difficult to cover the high spots. In this study we used flows of 1.0 - 1.5 c.f.s. on sloping land.

A border of alfalfa, 35 feet wide and 939 feet long was selected near Bernalillo on a clay loam which had an intake rate of 1.2 inches per hour in the upper third of the border. Both the surface texture and the intake rate were similar to that of the field shown in figure 2; however, the slope was much steeper in this study. You can see in figure 9 that there was a uniform grade of 0.7% for the first 600 feet, whereas, the lower end of the border had a grade of 0.2% with a rise of 0.4 foot at the end of the border. Furthermore, the storage capacity of the 0-5 foot root zone was more than twice that of 0-2 foot root zone shown in figure 2.

Samples taken before the first irrigation in 1947 on April 7 showed that poor penetration had been obtained the previous fall. In the upper half of the border the soil was dry, whereas it was approaching field capacity in the lower part of the border. On April 7, 3.2 inches of water was measured onto the border in 98 minutes with a median discharge of 1.5 c.f.s. Owing to side slope, numerous checks were necessary in order to cover the high spots. The water was cut off at the flume when the water had reached a point 780 feet distant, since the borders in the lower third were ready to break. Note in figure 9 that the water failed to penetrate beyond a depth of two feet in the upper third of the border. Here, the net gain averaged 2.3 inches of soil moisture, whereas, the soil had an available storage capacity of at least six inches of soil moisture. In order to bring the entire root zone to field capacity in the upper third (0.7% slope), it would be necessary to run water for five hours since the intake rate is 1.2 inches per hour. In contrast, applying water for 1.3 hours on the field shown in figure 2 resulted in a leaching irrigation on a 0.1% slope on a soil of moderate depth. So for soils of similar intake rate, we must consider both the storage capacity of the soil and the time that water remains on the area in selecting the proper sized stream for irrigation.

Although the grade was uniform, there was so much side slope that we did not try to use 0.5 c.f.s. Instead, we irrigated May 21 using 1.2 c.f.s. which resulted also in shallow penetration in the upper third of the border. Deeper penetration from this irrigation would have been expected since the alfalfa was beginning to bloom. Owing



Net gain 2 days after irrigation. Before irrigation. Date April 7, 1947. Median discharge 1.5 c.f.s. Water applied 3.2". Time applied 98 minutes. Cut off 780' from the flume. Size of area 35' x 939'. Crop-alfalfa-growth 1" high.

FIGURE 9. Border irrigation trial on clay loam topsoil, soil unit 2321, Silva farm near Bernalillo, N.M. Before irrigation the soil was dry in upper half of the border.

CONCLUSIONS: Inadequate penetration in the upper half of border may be remedied by decreasing discharge, increasing application time and by minor leveling to reduce side slope.

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to this growth, water should have remained a longer time on the upper third, as compared with the first irrigation when growth had hardly begun. Nevertheless, under the conditions of this study, flows of water in excess of 1.0 c.f.s. result in the water being cut off too soon for the 0.7% slope. Since there is no provision for tail water, it is not possible to irrigate with such flows for a longer period of time. Certainly, the sharp rise at the end of the border is undesirable.

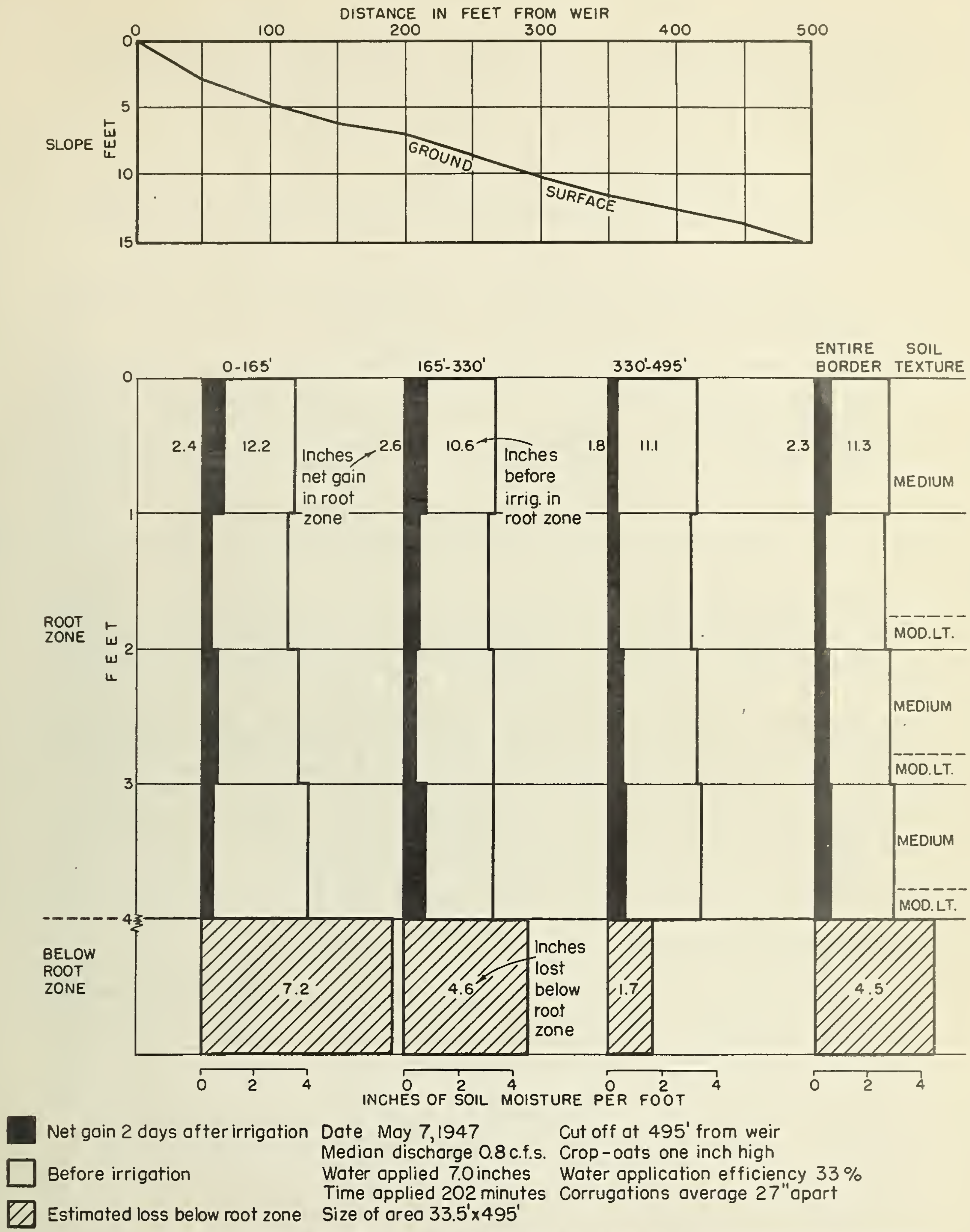
These trials show that inadequate penetration occurred on a 0.7% slope in the upper third of the border when flows of 1.0-1.5 c.f.s. were used. If the side slope was reduced by minor leveling, flows varying from 0.5-0.8 c.f.s. might prove to be satisfactory. Such studies are needed before recommending that the length of run be shortened or that the entire area be leveled to uniform grade.

CORRUGATION - DISCHARGE .5-1.0 c.f.s.
Uneven Grade 3%, Permeable Loam Soil Unit 3331

On slopes steeper than 1%, border irrigation is usually replaced by corrugation. Just as in border irrigation, extra long runs on soils with high intake rates result in leaching irrigations. Over-irrigation causes the water table to rise on lower lying areas and a subsequent reduction in crop yields. On the other hand, farmers object to short runs so we shall also consider how the condition of the surface soil affects irrigation efficiency.

An area of oats, 33.5 feet wide and 495 feet long, was selected in the San Juan valley near Farmington. In this area there were 15 corrugations spaced 27 inches apart. Corrugating had left the heavy loam soil rough and cloddy. Figure 10 shows that the slope was uneven and averaged 3%. We especially wanted to know if 495 feet was the correct length of run since the corrugations had been 900 feet long previously.

Owing to the drying out of the cloddy surface soil, the oats had germinated poorly. In order to get more oats up, the field was irrigated May 7, 1947. For the first 1.4 hours water was applied at the rate of 19 gallons per minute per corrugation. Since we were irrigating 15 corrugations, the 281 gallons per minute was equivalent to 0.6 c.f.s. (448 gallons per minute equals 1 c.f.s.). When it appeared that this rate would result in over-irrigation owing to the slow movement of water down the slope, the flow was increased to 30 gallons per minute. This rate caused excessive erosion and the amount applied was reduced to the original rate. A total of seven inches of water was applied in 3.36 hours with a very small loss of tail water. The intake rate for the entire area averaged 3.5 inches per hour. Owing to this high intake rate, the rate of movement was so slow that nearly three times as much water was applied to the upper third as to the lower third. Nevertheless, all parts of the border received a leaching irrigation. We estimated that this cloddy soil permitted more than seven inches of water to pass beyond a depth of four feet in the upper third of the area (figure 10). The average loss beyond the root zone for the entire border was 4.5 inches of water. Undoubtedly some of this water reached the water table inasmuch as the substratum was close



Date May 7, 1947
Median discharge 0.8 c.f.s.
Water applied 7.0 inches
Time applied 202 minutes
Size of area 33.5'x495'

Cut off at 495' from weir
Crop-oats one inch high
Water application efficiency 33 %
Corrugations average 27" apart

FIGURE 10. Corrugation trial on a deep medium textured soil, soil unit 3331 on Troy King farm near Farmington. The soil was very cloddy and was irrigated owing to poor germination of oats.
CONCLUSIONS: Excessive use of water was caused by cloddy surface and the length of corrugation was too long.

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to field capacity prior to irrigation. Such over-irrigation must contribute to the rising water tables on the lower lying areas. In this case the water application efficiency was only 33%. This low efficiency appears to have been caused by leaving the soil too cloddy.

The next irrigation was made June 7 when 6.7 inches of water were applied. The 0-4 foot depth gained but 2.6 inches, thus allowing 3.7 inches of water to pass beyond the four-foot depth. Again the cloddy surface soil caused excessive water losses on a 3% slope.

Quick tests show that some nitrates and ammonia were held presumably in the ridges in spite of leaching irrigations.

From these two trials we may conclude that a cloddy heavy loam soil may so retard the movement of water down the slope that low water application efficiency results. We need additional information pertaining to the reduction of intake rate through breaking down the clods to smaller sizes before determining the proper length of run.

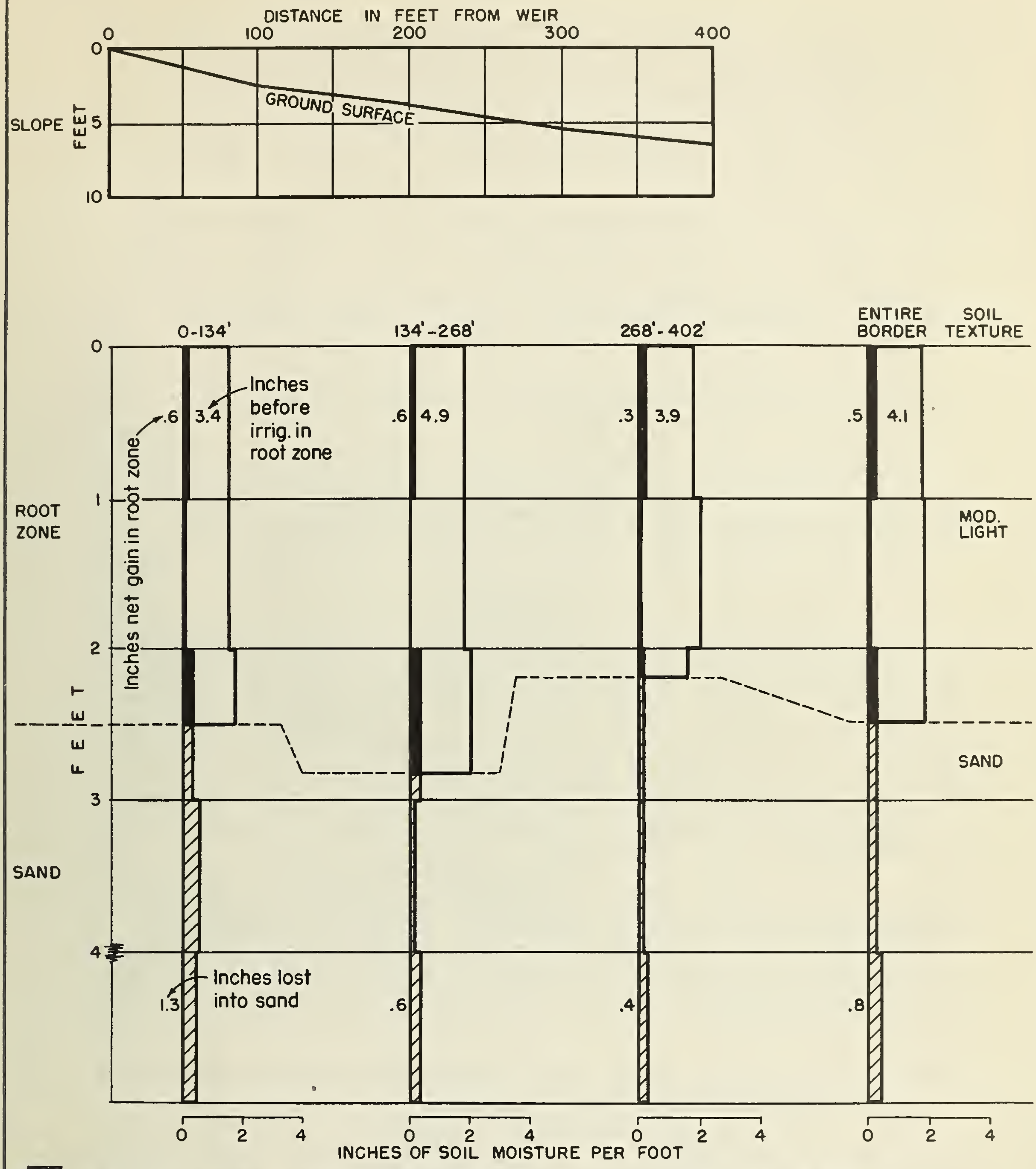
ROW IRRIGATION - DISCHARGE 0.05 c.f.s.
Uneven Grade 1.6%, Slowly Permeable Sandy Loam, Soil Unit 4451

You have just seen in the preceding study that a cloddy heavy loam had a rapidly permeable intake rate. Our next study area was row irrigated on a sandy soil to which the farmer applied water for eight hours or longer. Surely, we thought, this would be over-irrigation.

An area of potatoes, six rows wide, spaced 32 inches apart, and 402 feet long, was selected in the San Juan Valley near Farmington. The potatoes were in bloom at the time of the studies. You can see in figure 11 that the slope averaged 1.6%. The soil was a sandy loam containing considerable coarse and medium sand. Normally, we would expect this soil to be rapidly permeable; however, farm machinery had compacted the surface soil. The volume weight at a depth of 4-6 inches was 1.62 in contrast to the volume weight of 1.52 for the subsoil. We shall now consider the extent to which this compaction has reduced the intake rate.

On May 22, 1947, 16 days after the previous irrigation, 3.3 inches of water were measured onto the area in 7.6 hours. The loss of tail water was 0.1 inch. From this irrigation the root zone showed a net gain of but two inches of water four days after irrigation. At a depth of 30-48 inches, an additional 1.6 inches of soil moisture were stored; but this may be considered as a loss since no roots were observed in this layer. The water application efficiency of this irrigation was only 61%. The average intake rate for the entire study areas was only 0.5 inch per hour on this sandy loam soil. A more efficient use of water would have been obtained if the flow of water had been cut off at the end of four hours instead of 7.6 hours.

The next irrigation measured was 16 days later on June 9 at which time the entire root zone was close to field capacity. Each row received the equivalent of 3.5 gallons per minute for a period of 7.3 hours, whereas 5.3 gallons per minute were applied on May 22.



Net gain 3 days after irrigation

Estimated loss into sand

Before irrigation

Date June 9, 1947

Median discharge 0.046 c.f.s.

Water applied 2.1 inches

Water application efficiency 24%

Tail water .5 inches

Time applied 438 minutes

Size of area 16' x 402'

FIGURE 11. Row irrigation trial of potatoes, 32" rows, on a moist sandy loam topsoil, soil unit 4451, August Schmidt farm near Farmington, N.M. CONCLUSIONS: This irrigation was not needed. Increasing the discharge and increasing infiltration rate would reduce excessive use of water.

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This difference in rates shows the need for determining the maximum non-erosive flow. The volume of tail water was 0.5 inch. Although only 2.1 inches of water were applied during this long period, the entire root zone showed a gain on only 0.5 inch of soil moisture three days later (figure 11). The water application efficiency was only 24%. Even this low efficiency would have been lower if the intake rate had not dropped to 0.2 inch per hour. Again we can see that the water was held on the study area for too long a period. The time of application should be reduced and could be shortened still further if the normal intake rate was maintained by keeping farm machinery off when the soil is at or near field capacity. Additional information is needed, such as the maximum flow of water which could be applied without causing erosion.

Quick tests show that some ammonia and nitrates were held in the ridges in spite of leaching irrigations.

From these trials, we may conclude that a compact sandy loam has a slowly permeable intake rate. Furthermore, that the water was allowed to run too long and that both irrigations were leaching irrigations because water was lost beyond the root zone.

NET GAIN

In 25 out of 32 irrigations for a wide range in soils, less than three inches of water were stored in the root zone two days after irrigation. The depth of the root zone varied from 20 to 36 inches in eight areas and from 36 to 60 inches in the other two. Under the conditions of this study as little as two inches of water should be applied if the nitrates are to be held in the upper part of the root zone under border irrigation. Such small quantities of water cannot be applied without changes in irrigation practices on the permeable soils studied.

Until irrigation trial date are available for specific areas, textures varying from medium to heavy may be combined for estimating the expected net gain in the surface soil, subsoil, and substratum. Table 1 shows the maximum and average net gain for three separations of alluvial soils which are not affected by alkali, water tables, and are non-gravelly.

TABLE 1. Net gain two days after irrigation expressed as inches/foot (tentative)

	Surface		Subsoil		Substratum	
Texture	Max.	Aver.	Max.	Aver.	Max.	Aver.
1, 2, 3	2.1	1.4	1.8	0.9	1.5	0.6
4	1.5	1.0	1.2	0.6	1.0	0.4
5 or P	0.7	0.5	0.6	0.4	0.5	0.2

Although individual exceptions occur, the net gain two days after irrigation for soils of medium and heavier texture, moderately light

and light is about 3:2:1 ratio. The average maximum gain per foot of medium to heavy textured surface soils is 2.1 inches, whereas that of moderately light textures is 1.5 inches. Maximum gains in the subsoil are about 75-85% of the surface soil and 60-70% in the substratum. If all irrigations are included the average gain in the subsoil is only half of the maximum gain.

GRASS MULCHES

It should be pointed out that the grass mulches in this study were much heavier than those usually obtained from crops other than grass seed production under irrigated conditions. Furthermore, the available storage capacity of most of the soils studied was less than three inches of soil moisture. Since the grass mulches not only slowed up the speed of the water, but also increased the intake rate, excessive applications and losses of water resulted. A two-inch mulch on a clay soil necessitated an average application of 5.7 inches of water for three irrigations in order to cover a border 380 feet long. In 1946, after removing the mulch (figure 1) the average volume of water applied for four irrigations was only 4.1 inches or a saving of 1.6 inches of water. On a sandy loam soil the leaving of one heavy crop of sand lovegrass increased the time to irrigate one acre by 23 minutes and increased the volume of water required to cover the border by 0.6 inch. Under conditions pertaining to grass seed production, mulches have increased intake rates so that losses from the root zone of water and soluble nitrogen have occurred.

MEASURES FOR SAVING WATER

1. If feasible, level the land to uniform grade and eliminate side slope for border irrigation. Rougher areas can be used for either row irrigation or corrugations.

2. On permeable soils apply the minimum volume of water necessary to cover the area by cutting the water off when it reaches a set point or stake. At this set point, the water is cut off at the maximum distance from the end of the border that the water will satisfactorily cover the border.

3. Carry out irrigation trials on representative farms by using the following steps: (a) install a weir or flume on the area to be studied in order to measure the amount of water being applied. (b) Take soil moisture samples by one-foot depths before and after irrigation in order to determine the depth of penetration and the net gain of water in the root zone from any given irrigation. (c) Determine the intake rate of the study area by dividing the net gain by the time that the water remained on the surface of a given portion of the border. Devise an irrigation system which applies the minimum volume of water necessary to fill the root zone.

APPLICATION OF THE RESULTS

Most of the irrigation trials and soil moisture studies were conducted on permeable soils underlain by sand at a depth varying from 20 to 36 inches. The effects of uneven grades upon excessive losses of water should apply to permeable soils which are border irrigated in New Mexico, Colorado, Utah and parts of Arizona. The excessive use of water in row irrigated and corrugated areas should apply to northern New Mexico, Colorado and Utah. The excessive water losses caused by mulches on permeable soils of course, may not apply to slowly permeable soils. The high losses of soluble nitrogen reported from the areas used for grass seed production should apply to other crops which are heavily fertilized with commercial nitrogen. The tentative table of maximum net gains should be satisfactory in the irrigated areas of New Mexico, Colorado, and Utah except the mountain meadows. The average net gain data will require adjustment depending upon the tendency to irrigate sooner than needed. More, of course, needs to be done in order to evaluate net gain two days after irrigation, especially on the moderately light textured surface soils. There is also need for more rate of intake data: (1) the range of values which might be expected during a rotation, and (2) the effect of tillage, mulches, amendments, structure and compaction upon the intake rate. Thus, irrigation systems may be designed which will most efficiently apply the minimum volume of water necessary to fill the root zone and to retain plant food.